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Modelling of axial magnetic field effect on electric arc in ablation capillaries

A. Wolny, J. Piotrowski
Gdańsk University of Technology

Modelling of the axial magnetic field effect on the arc voltage of an arc burning in a gas-evolving chamber using Niemeyer's model of ablation arcs is discussed. The results support the assumption that the arc voltage rise is due to the increasing gas generation.

1. Introduction

In previous publications [1,2] the authors showed a significant effect of the axial magnetic field on the arc voltage of an arc burning in gas-evolving capillary chambers. Under similar conditions the magnetic field perpendicular to the arc column caused no voltage changes. It was noticed that the axial field influenced the arc voltage almost proportionally. The highest voltage increase was recorded for organic materials. At the field density reaching several tesla, the arc voltage rise by 300%, and more was observed, Fig. 1.

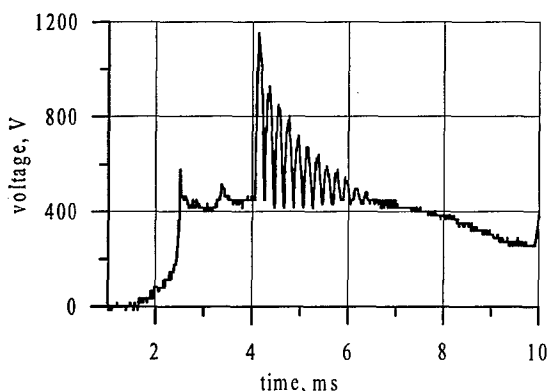


Fig. 1. Effect of high frequency axial magnetic field on ablation arc voltage: PE capillary, 1-mm \varnothing [2]

When the arc was stabilised by a ceramic capillary or quartz-sand the magnetic field effect was negligible.

2. Discussed phenomenon

The arcing voltage is proportional to the arc deposited power. Hence, followed the above-given observations the presence of magnetic field influences the energy balance of an arc burning in a gas-evolving capillary, or in other words – arc cooling conditions. Moreover, it was noticed that such influence can only be exerted by the axial magnetic field component contracting the arc column. Thus, it can be assumed that the observed process consists of the following steps:

reduction of the arc column diameter \rightarrow increase of the arc resistance \rightarrow increase of power deposition \rightarrow the arc temperature rise \rightarrow intensification of radiation \rightarrow abundant evaporation of walls \rightarrow improvement of the convection cooling effect \rightarrow further reduction of

the arc column diameter leading to the adjustment of energy balance.

The assumption of such procedure permits to rely on ablation arc models in the modelling of the magnetic field effect on the arcing voltage. To practical models belongs that one developed by Niemeyer [3], and improved later by Ruchti Niemeyer [4]. These authors provided in addition practical examples of calculations complemented with experiments.

3. Application of Niemeyer's model

Niemeyer's model is cylindrical, one-dimensional and isothermal. It consists of two-layer cylindrical arc column, with current conducting central core and the outer layer filled with hot wall vapours. In this model the only flowing mass source is the vaporising chamber wall. The boundary temperatures can be defined easily. The outer temperature is dependent on the pyrolysis of wall material and the inner one, defined for the surface separating the layers, is connected with the assumed plasma conductivity. For approximate calculations both of them can be considered nearly constant.

The deposited energy in the current conducting core is inversely proportional to the plasma conductivity and cross-sectional area of the core. It is partly transferred to the chamber wall causing its vaporisation, and partly taken off by the cool stream of vapours generated by the wall streaming axially.

The axial magnetic field contracts the arc column core and reduces its cross section raising this way the energy deposited, and consequently, the arc plasma enthalpy, temperature, radiation, and vapour flow streaming from the walls increasing the pressure.

The hydromagnetodynamic equations describe above-discussed processes, if plasma parameters and radiation conditions are known. Niemeyer applied black-body model.

Since the magnetic field does not increase the energy of charged particles, its only effect is the arc core diameter reduction. Hence, the analysis of the magnetic field influence can be roughly performed based on the latter process.

4. Simulation of magnetic field effect

In the simulation material parameters were calculated based on the Kovitya's model [5], and functions of temperature and pressure were designed. Although a lot of materials were tested, PTFE was selected as the wall

material to facilitate comparison of the obtained results with those of Niemeyer [3].

In the first step the simulation was performed under Niemeyer's conditions, next arbitrary reduction of the arc core diameter was applied, and finally the needed magnetic field density was found.

The stagnation point temperature, pressure, electric field were calculated.

The results of simulation for 3-mm \varnothing , and no magnetic field conditions are provided in Fig. 2. Experimental check point has been marked.

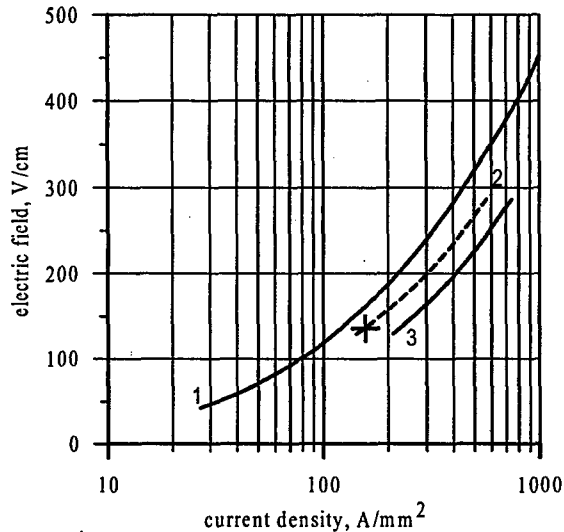


Fig. 2. Electric field along the arc column under no magnetic field conditions: 1 – Niemeyer's calculation, 2 – j for full arc cross section, 3 – j for actual arc core, \times – the ratio of the measured current to the full arc cross section

5. Experimental

In experiments PTFE capillary were used with the length of 20 mm and diameters taken from the range of 1–3 mm. Currents were supplied from capacitors.

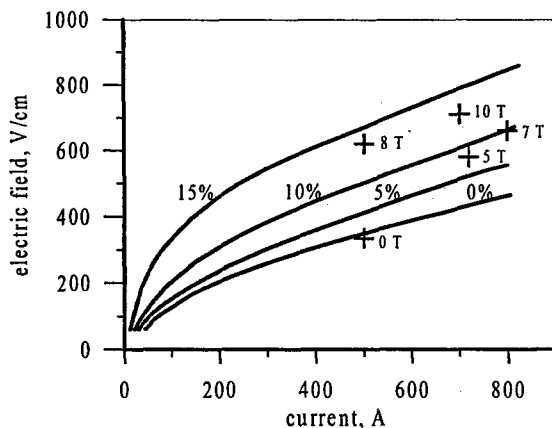


Fig. 3 Effect of arc core contraction on the arc electric field in a PTFE capillary of 1-mm \varnothing .

In Fig. 3 and Fig. 4 the simulation curves are marked with the percentage of arc core contraction. Next to the points of experimental measurements rounded applied magnetic field density is shown.

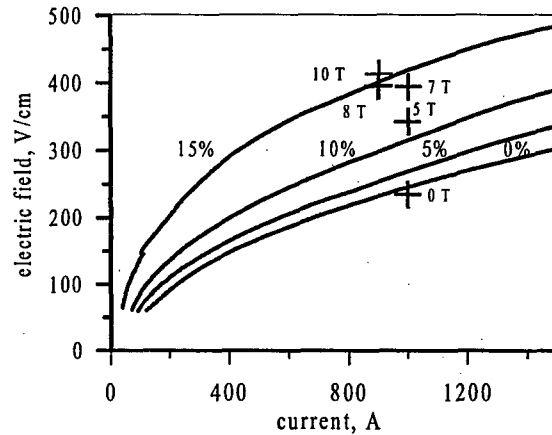


Fig. 4. Effect of arc core contraction on the arc electric field in a PTFE capillary of 2-mm \varnothing .

6. Discussion

Calculations were performed at the stagnation point, while measurements average values varying along the enclosure. Thus, making comparisons that fact should be taken under consideration. Quite moderate reduction in the arc diameter raises significantly the arc voltage, but the magnetic field rather needs radical changes.

7. Conclusions

Simplified simulation of the effect of axial magnetic field on the arc burning in gas-evolving capillary by exclusive consideration of reduction of the arc core diameter provides results convincing that this is the basic phenomenon responsible for the significant rise of arcing voltage.

A strong impulse of axial magnetic field can be used for the enforcement of current transfer from the arc to a parallel device.

Acknowledgements

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8. References

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